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Review Paper

ENERGY EFFICIENCY OF SOLAR COLLECTORS AND THEIR IMPACT ON THE ENVIRONMENT

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Abstract. *This paper compares the energy efficiency and environmental impact of solar collectors versus individual furnaces for the purpose of heating sanitary water in a five-person household. The heat calculation results from the water heating collectors are proposed, along with the necessary number of solar collectors for the aforementioned household in Niš month by month. The amount of lignite needed to calculate the thermal power of lignite for heating water is shown, along with the calculations' results for the mass value of the pollutants released during lignite's complete combustion (kJ/kg) and their retention times in the atmosphere for a day and a month, from April to November.*

Key words: *solar energy, thermal energy, solid fuels, emissions, energy efficiency.*

1. INTRODUCTION

Solar energy means a modern field of energy that is based on passive (direct) and active (indirect) capture of solar radiation. Active capture of solar radiation is performed on solar collectors that are installed on a given object. On Earth, solar radiation can be used to heat water, air or other materials.

The technologies of using conventional energy sources are well known and widely used around the world. However, serious air pollution issues are associated with the use and combustion of solid fuels (coal).

Thermal power plants use large amounts of coal. Gaseous pollutants like carbon (II) oxide (CO), carbon (IV) oxide (CO_2), sulfur oxides (SO_x), nitrogen oxides (NO_x) and easily volatile hydrocarbons are released into the atmosphere when wood, coal, oil, and natural gas are burned. In addition to gaseous pollutants, there is smoke and soot. The composition of the

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released smoke includes tiny particles of metals and their oxides, as well as fine particles of carbon, ash, oil, and fat. As a result, they have many negative effects on the environment such as: the greenhouse effect, acid rain, human health impact, phytotoxic effect, etc.

The total annual emission of pollutants released from the combustion of certain types of natural fuels is reduced by the application of flat collectors [1,2].

2. SOLAR COLLECTORS

Flat collectors are used for low-temperature conversion of solar radiation (t <100 ° C).

Depending on the construction and purpose, flat collectors are divided into collectors for water heating (water) and collectors for air heating (air). Solar collectors consist of a box, front cover, absorber, thermal insulation and protection on the back. The collector box is usually made of anodized aluminum. Glass or heat-resistant plastic foil is used as the front cover. Aluminum sheet is used for protection on the back.

The efficiency of flat collectors depends on their construction, front cover, absorber and thermal insulation.

The speed of the wind flow, the angle of incidence of the solar radiation, etc., affect the efficiency of the collector. The efficiency of the collector decreases as it ages because of the deterioration processes on the front cover, absorber, and thermal insulation.

Collector connections can be in series and parallel. The solar system with forced water circulation consists of solar collectors, a solar water heater, a differential thermostat, a pump, an expansion vessel, and corresponding return and non-return valves.

Solar collectors are most often used for heating water in residential buildings, motels, hotels, sports facilities, industrial facilities, etc.

The heat required to heat water using solar collectors is calculated using the following expression:

$$Q = \frac{nm}{3600} c(t_{iz} - t_{ul}) \left[\frac{\text{kwh}}{\text{day}} \right] \tag{1}$$

The formula is valid from April to November.

In the formula:

n – the number of household members
m – the mass of water per household member during the day (kg/day)
c – 4,18 kJ/kg °C - specific heat of water
t_{ou} – water temperature at the outlet of the collector (°C)
t_{in} – water temperature at the inlet of the collector (°C).

The required number of collectors is calculated using the following formula:

$$N = \frac{Q}{Q_S S_k \eta} \tag{2}$$

where:

Q – heat required for water heating [kwh/day]
Q_s – solar radiation energy that falls on 1m^2 of collector during the day [kwh/m^2]
S_k – the surface area of one collector [1m^2]
η – efficiency of the collector [4].

3. CONVENTIONAL HEAT SOURCES

Classical-conventional thermal energy sources include: wood, coal, oil, natural gas, etc.

3.1. Combustion of Coal - Lignite

Combustion of coal emits solid particles (fly ash), which mainly consist of carbon, silicon, aluminum and iron oxide. In addition to solid particles, the combustion of coal also produces various gases: carbon dioxide, sulfur oxides, nitrogen oxides, carbon monoxide, hydrocarbons and others. Most coals contain significant amounts of sulphur. During combustion, sulphur from coal is converted into sulfur dioxide, which is released into the atmosphere, with a portion remaining in the form of sulfate in the ash. Nitrogen oxides are formed during the combustion of coal, partly as a consequence of the reaction of oxygen and nitrogen from the air at high temperatures. The efficiency of coal combustion depends on the content of other compounds in the flue gases: carbon monoxide and carbon-hydrogen [7].

The thermal power of the fuel means the amount of heat that is released during the complete combustion of the fuel and is expressed in (kJ/kg), for solid fuels [3].

The thermal power of coal is given in Table 1.

Table 1 Coal Thermal Power

Energy Fuel	Lower Thermal Power of Fuel (Hd)		Sulphur Content S (%)	Hygroscopic Moisture Content (%)	Content of Incombustible Matter (%)
	(kJ/kg)	kWh/kg			
Lignite	7000-12000	1,94-3,33	0,5-1,5	30-50	8-20

3.2. Calculation of the Mass of Pollutants Emitted the Combustion of Conventional Fuels for Heating Water in a Five-person Household

The following formula is used to calculate the mass of pollutants emitted:

$$m_p = m_g EF \text{ [kg]} \tag{3}$$

where:
m_p – the mass of emitted pollutants
m_g – the mass of fuel [kg]
EF – lignite emission factor [kg/1000kg]

4. IMPACT OF SOLAR COLLECTORS ON THE ENVIRONMENT

Solar energy is pure and is available in unlimited quantities. Components of solar systems are produced with state-of-the-art, environmentally friendly technologies. They work flawlessly, do not emit harmful substances and do not emit harmful electromagnetic radiation into the environment. Recycling solar system components is also acceptable. Solar systems do not negatively affect the environment and do not generate any noise or chemical pollutants during use.

During operation, solar systems do not emit gaseous or liquid pollutants, as well as radioactive substances [9].

5. Calculation of Emissions of Pollutants Resulting from the Combustion of Natural Fuels

The emission factor is the ratio of the quantity of emitted pollutant (3) and the quantity of used fuel [10]:

$$\text{Emission factor } (EF) = \frac{\text{quantity of emitted pollutant}}{\text{quantity of used fuel}}$$

Table 2 The emission factors and time of residence in an atmosphere of gaseous pollutants released from lignite.

Pollutants	Emission Factor EF [kg/1000kg] of lignite	Residence Time in Atmosphere
Aldehydes (HCHO)	0,002	-
Carbon (II) Oxide (CO)	22,680	less than 3 years
Methane (CH_4)	4,536	about 4 years
Nitrogen Oxides(NO_x)	3,629	about 5 days
Sulfur Dioxide (SO_x)	17,235	about 4 days

6. Results

6.1. Calculation of Heat Obtained through Heating Collectors for Sanitary Water for a Five-member Household

$$Q = \frac{nm}{3600} c(t_{iz} - t_{ul}) \ \frac{\text{kwh}}{\text{day}} \tag{4}$$

in which the following data is entered:
$n = 5$; $m = 80$kg; $t_{iz} = 45$°C; $t_{ul} = 15$°C

By substituting the above data in equation (1), the required amount of thermal energy for heating water for a five-member household using solar collectors is obtained:

$$Q = 13,92 \ \frac{\text{kwh}}{\text{day}}$$

6.2. Calculating the Number of Collectors for Heating Water for a Five-person Household Using Collectors by Months from April to November

If in the Eq. (5)

$$N = \frac{Q}{Q_S S_k \eta} \tag{5}$$

the following data are entered:

$$Q = 13,92 \ \frac{\text{kwh}}{\text{day}}$$

Q_S – values for solar energy in Niš are given in Table 3.

Table 3 Values for solar energy for the city of Niš

Month	$Q_S\left[\frac{\text{kwh}}{\text{m}^2}\right]$
April	4790
May	5720
June	6660
July	6860
August	6160
September	4280
October	2970

S_k = 1m^2 – the surface area of one collector
η = 0,4 – the efficiency of the collector

The required number of collectors per month is obtained and is given in Table 4.

Table 4 Required number of collectors for water heating for a family of five in Niš, by months

Month	Number of collectors
April	3,63
May	3,04
June	2,6
July	2,53
August	2,82
September	4,06
October	5,85

6.3. Calculating the Amount of Lignite for Water Heating for a Five-member Household

The formula is used to calculate the amount of lignite for heating water for a five-member household (6):

$$Q = m_g \cdot H \text{ [kwh]} \tag{6}$$

It follows that

$$mg = \frac{Q}{H} \text{ [kg]} \tag{7}$$

of lignite:

By substituting in (7), Q = 13,92 [kwh/day] and H = 2,63 [kwh/kg] – it turns out that 80l of water is needed to heat

m_g = 5,29 kg/day of lignite.

The amount of solid fuels needed to heat sanitary water per month for a five-member household was obtained by multiplying the value of mg of fuel by the number of days in a given month which is given in Table 5.

Table 5 The amount of lignite for heating sanitary water per month for a five-member household

Month	Number of Days	Amount of Lignite
April	30	158,7
May	31	163,99
June	30	158,7
July	31	163,99
August	30	163,99
September	31	158,7
October	31	163,99
Total:	214	1132,06

6.4. Calculating the Value of the Mass of Emitted Pollutants Generated by the Combustion of Lignite for Heating Water in a Five-member Household

Using the formula for the values of the emission factor for lignite given in Table 2, the mass of pollutants emitted (kg) as a result of the combustion of lignite for heating water for a five-person household was calculated for each month. The obtained results are given in Table 6.

Table 6 LCIA calculation of masses of emitted pollutants resulting from the combustion of lignite for heating water for a five-member household

Month	Number of Days	Mass of Emitted Pollutants, Lignite [kg]				
		Aldehydes (HCHO)	Carbon (II) Oxide (CO)	Methane (CH_4)	Nitrogen Oxides (NOx)	Sulfur Dioxide (SOx)
April	30	$3{,}17\ 10^{-4}$	3,59	0,71	0,57	2,73
May	31	$3{,}27\ 10^{-4}$	3,79	0,74	0,59	2,79
June	30	$3{,}17\ 10^{-4}$	3,59	0,71	0,57	2,73
July	31	$3{,}27\ 10^{-4}$	3,79	0,74	0,59	2,79
August	30	$3{,}17\ 10^{-4}$	3,59	0,71	0,57	2,73
October	31	$3{,}27\ 10^{-4}$	3,79	0,74	0,59	2,79
Total	214	$6{,}44\ 10^{-4}$	7,31	1,45	1,16	5,52

Based on the results obtained in this paper, the following can be concluded:

Solar energy as a renewable energy source has gained multiple significance compared to the use of conventional energy sources-lignite, which is used to heat the water of a five-member household and whose combustion in the atmosphere produces heavy metals (aldehydes, Carbon (II) Oxide (CO) and Methane (CH_4), which lead to the greenhouse effect. The paper presents a calculation of the total amount of heat required for water heating using solar collectors for a five-member household, which is 13.92kwh/day.

The required number of collectors per month is calculated using the values for solar radiation energy for Niš in Table 3 that is absorbed on the surface of one collector, as shown in Table 4. It is necessary to install 4 collectors in Niš.

The total amount of fossil fuel needed to heat sanitary water per month for a five-person household is 5.29 kg/day, given in Table 5, whose combustion in the atmosphere emits a total of $2.14x10^{-4}mg/m^3$ of pollutant emissions given in Table 6.

The emission factor is given, as well as the residence time of the emitted pollutants and the amount of fuel used. The use of solar collectors for water heating will reduce the total amount of pollutants emitted by the combustion of the conventional energy source - lignite.

The installation of solar collectors contributes to the better use of available energy resources and the reduction of pollution for people and the protection of the environment.

7. CONCLUSION

Based on the results obtained in this paper, the following can be concluded:

In the months of April to October, 5.29 kg/day of lignite is required to heat the water of a five-member household in Nis using the traditional energy source - lignite. The total emission of pollutants emitted during lignite combustion is $6{,}44x10^{-4}$, Carbon (II) Oxide (CO) and Methane (CH4) into the air, with the greenhouse effect, which leads to climate change and the consequences for people, flora, fauna and materials.

Solar energy is used to heat water using solar collectors from April to October. If the volume of hot water is 80 l/day, for a family of five in Niš, it is necessary to install 4 collectors. The computational approach is based on the solar radiation model (r.sun model), and the spline interpolation techniques (s.surf.rst and s.vol.rst) applied in the GIS open source GASS software.

Nomenclature

n – number of household members;
m – the mass of water/lignite per household member during the day (kg/day^{-1});
c – 4.18 (kJ/kg^{-1}) specific water heat (°C)
t_{ou} – water temperature at the outlet of the collector(°C),
t_{in} – water temperature at the inlet to the collector (°C).
Q – heat required for water heating (kwh/day^{-1})
Q_s – solar radiation energy that falls on $1m^{-2}$ collectors during the day (kwh/m^{-2})
S_k – surface area of one collector ($1m^{-2}$)
η – the efficiency of a collector
m_p – the mass of emitted pollutants
m_g – the mass of fuel (kg^{-1})
EF – emission factor of lignite ($kg/1000kg^{-1}$)
N – collector efficiency.

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ENERGETSKA EFIKASNOST SOLARNIH KOLEKTORA I NJIHOV UTICAJ NA ŽIVOTNU SREDINU

Rad se bavi određivanjem energetske efikasnosti i uticajem solarnih kolektora na životnu sredinu, u odnosu na individualne peći za zagrevanje sanitarne vode u petočlanom domaćinstvu. Dati su rezultati izračunavanja toplote koja se dobija pomoću kolektora za zagrevanje vode, kao i potreban broj solarnih kolektora za domaćinstvo u Nišu po mesecima. Prikazani su rezultati izračunavanja potrebne količine lignita za zagrevanje vode, data je toplotna moć lignita kao i rezultati izračunavanja vrednosti mase emitovanih zagađujućih supstanci koje nastaju pri potpunom sagorevanju lignita (kJ/kg) i vreme zadržavanja u atmosferi za dan, mesec u periodu od aprila do novembra.

Ključne reči: *solarna energija, toplotna energija, čvrsta goriva, emisija, energetska efikasnost.*